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Sirpa Kleemola and Martin Forsius (eds)

8th Annual Report 1999

UN ECE Convention on Long-Range Transboundary Air Pollution

International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems

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wge Working Group on Effects of the Convention on Long-Range Transboundary Air Pollution

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Cover photo: Intensive vegetation monitoring plot in the integrated monitoring area of Valkea-Kotinen
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Contents

Summary

Background and objectives of the programme

Integrated monitoring of ecosystems means physical, chemical and biological measurements over time of different ecosystem compartments simultaneously at the same location. In practice, monitoring is divided into a number of compartmental subprogrammes which are linked by the use of the same parameters (cross-media flux approach) and/or same or close stations (cause-effect approach).

The International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM) is part of the Effects Monitoring Strategy under the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP). The main objectives of the ICP IM are:

- Monitor the biological, chemical and physical state of ecosystems (catchments/plots) over time in order to provide an explanation of changes in terms of causative environmental factors, including natural changes, air pollution and climate change, with the aim to provide a scientific basis for emission control.

- Develop and validate models for the simulation of ecosystem responses and use them (a) to estimate responses to actual or predicted changes in pollution stress, and (b) in concert with survey data to make regional assessments.

- Carry out biomonitoring to detect natural changes, in particular to assess effects of air pollutants and climate change.

The full implementation of the ICP IM will allow ecological effects of heavy metals, persistent organic substances and tropospheric ozone to be determined. A primary concern is the provision of scientific and statistically reliable data that can be used in modelling and decision making.

The ICP IM sites (mostly forested catchments) are located in undisturbed areas, such as natural parks or comparable areas. The ICP IM network presently covers about 50 sites, with on-going data submission, in 22 countries. The international Programme Centre is located at the Finnish Environment Institute in Helsinki. The present status of the monitoring activities is described in detail in Section 1 of this report.

A manual detailing the protocols for monitoring each of the necessary physical, chemical and biological parameters is applied throughout the programme (Manual for Integrated Monitoring 1998).

Recent assessment activities within the ICP IM

Assessment of data collected in the ICP IM framework is carried out at both national and international levels. Key tasks of recent assessment acticvities regarding international ICP IM data have been:

- Input-output and proton budgets
- Trend analysis of bulk and throughfall deposition and runoff water chemistry
- Assessment of biological data using multivariate gradient analysis
- Dynamic modelling and assessment of the effects of different emission/ deposition scenarios

Conclusions from recent international studies

Input-output and proton budgets

Ion mass budgets have proved to be useful for evaluating the importance of various biogeochemical processes that regulate the buffering properties in ecosystems. Long-term monitoring of mass balances and ion ratios in catchments/plots can also serve as an early warning system to identify the ecological effects of different anthropogenically -derived pollutants, and to verify the effects of emission reductions.

The first results of input-output and proton budget calculations were presented in the 4th Annual Synoptic Report (ICP IM Programme Centre1995) and the updated results regarding the effects of N deposition were presented in Forsius et al. (1996). Data from selected ICP IM sites were also included in a European study for evaluating soil organic horizon C:N ratio as an indicator of nitrate leaching (Dise et al. 1998).

The budget calculations showed that there was a large difference between the sites regarding the relative importance of the various processes involved in the transfer of acidity. These differences reflected both the gradients in deposition inputs and the differences in site characteristics. The proton budget calculations showed a clear relationship between the net acidifying effect of nitrogen processes and the amount of N deposition. When the deposition increases also N processes become increasingly important as net sources of acidity.

A critical deposition threshold of about 8-10 kg N ha^{-1} a^{-1}, indicated by several previous assessments, was confirmed by the input-output calculations with the ICP IM data.The output flux of nitrogen was strongly correlated with key ecosystem variables like N deposition, N concentration in organic matter and current year needles, and N flux in litterfall. Soil organic horizon C:N-ratio seems to give a reasonable estimate of the annual export flux of N for European forested sites receiving throughfall deposition of N up to about 30 kg N ha^{-1} a^{-1}. Such statistical relationships from intensively studied sites could be efficiently used in conjugation with regional monitoring data (e.g. ICP Forests and ICP Waters data) in order to link process level data with regional-scale questions.

A scientific strategy to carry out further data assessment on stores and fluxes of heavy metals has been developed within the ICP IM. This work is lead by the National Focal Point of Sweden. The strategy is documented in Section 3 of this report.

Trend analysis

Empirical evidence on the development of environmental effects is of central importance for the assessment of success of international emission reduction policy. First results from a trend analysis of monthly ICP IM data on bulk and throughfall deposition as well as runoff water chemistry were presented in Vuorenmaa (1997). ICP IM data on water chemistry have also been used for a trend analysis carried out by the ICP Waters and presented in the 9-years report of that programme (Lükewille et al. 1997).

As a consequence of reduced sulphur deposition, the non-marine sulphate and hydrogen ion (H^+) concentrations in runoff water have declined at most ICP IM sites in Nordic countries in 1988-1995. Decreasing nitrate concentrations are also commonly observed. For sites in other regions the nitrogen results are more difficult to interpret. Signs of developing nitrogen saturation (changes in soil chemistry and seasonal nitrogen leaching) have been detected for certain catchments in Sweden. These results suggest that nitrogen needs special attention in any further work.

Assessment of biological data using multivariate gradient analysis

The effect of pollutant deposition on natural vegetation, including both trees and understorey vegetation, is one of the central concerns in the impact assessment and prediction. The first assessment of vegetation monitoring data at ICP IM sites with regards to N and S deposition was carried out by Liu (1996). Vegetation monitoring was found useful in reflecting the effects of atmospheric deposition and soil water chemistry, especially regarding sulphur and nitrogen. The results suggested that plants respond to N deposition more directly than to S deposition with respect to vegetation indices.

De Zwart (1998) carried out an exploratory multivariate statistical gradient analysis of possible causes underlying the aspect of forest damage at ICP IM sites. These results suggested that coniferous defoliation, discolouration and lifespan of needles in the diverse phenomena of forest damage are for respectively 18%, 42% and 55% explained by the combined action of ozone and acidifying sulphur and nitrogen compounds in air.

From the present and previous ordination exercises it was concluded that the applied statistical techniques are capable of revealing underlying structure and possible cause-effect relationships in complex ecological data, provided that analysed gradients have an adequate range to be interpolated. Since the data obtained was unexpectedly poor in the span of environmental gradients, the results of the presented statistical ordination only indicated correlative cause-effect relationships with a limited validity. The poor span of gradients could be attributed to the relative scarcity of biological effect data and the occurrence of missing observations both in the chemical and biological data sets. It was concluded, that the power of the vegetation monitoring in impact assessment would increase considerably with improvements in the ICP IM data reporting and inclusion of additional sites.

A scientific strategy to carry out further data assessment of cause-effect relationships for biological data, particularly vegetation, has been developed within the ICP IM. This work is lead by the National Focal Point of The Netherlands. The strategy is documented in Section 2 of this report.

Dynamic modelling and assessment of the effects of emission/ deposition scenarios

In a policy-oriented framework, dynamic models are needed to explore the temporal aspect of ecosystem protection and recovery. The critical load concept, used for defining the environmental protection levels, does not reveal the time scales of recovery. Dynamic models have been developed and used for the emission/ deposition scenario assessment at selected ICP IM sites (e.g. Forsius et al. 1997, 1998a 1998b, Posch et al. 1997). These models are flexible and can be adjusted for the assessment of alternative scenarios of policy importance.

These modelling studies have shown, that the recovery of soil and water quality of the ecosystems is determined by both the amount and the time of implementation of emission reductions. According to the models, the timing of emission reductions determines the state of recovery over a short time scale (up to 30 years). The quicker the target level of reductions is achieved, the more rapidly the surface water and soil status recover. For the long-term response (> 30 years), the magnitude of emission reductions is more important than the timing of the reduction. The model simulations also indicate that N emission controls are very important to enable the maximum recovery in response to S emission reductions. Increased nitrogen leaching has the potential to not only offset the recovery predicted in response to S emission reductions but further to promote substantial deterioration in pH status of freshwaters and other N pollution problems in some areas of Europe.

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ICP IM activities, monitoring sites and available data

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1.1 Review of the ICP IM activities in 1998-1999

- The sixth meeting of the Programme Task Force on ICP Integrated Monitoring was held in Tallinn, Estonia 20-22 April 1998.

- The IM Manual was finalized and presented at the Working Group of Effects meeting in August 1998. A WWW-version of the IM Manual was finalized in October 1998 (http://www.vyh.fi/eng/intcoop/projects/icp_im/manual/index.htm).

- A summary of the EU/LIFE project results on dynamic modelling and development of monitoring methods was prepared for the WGE meeting. A scientific paper on the results of dynamic model applications on ICP IM sites has been published.

- IM Programme participated in arranging a joint ICP Waters ICP IM Workshop on biological assessment and monitoring; Evaluation of methods and models. The workshop was held back to back with the Task Force meeting of ICP Waters in Zakopane, Poland 13-15 October, 1998.

- After October 1st 1998 the National Focal Points (NFPs) reported their 1997 results to the IM Programme Centre. The Programme Centre carried out standard check up of the results and incorporated them into the IM database.

- IM Programme Centre participated in the EU project 'Networking of Long-term Integrated Monitoring in Terrestrial Systems (NoLIMITS)'. Selected ICP IM sites were included in the pilot study of building a European Integrated Monitoring Information Exchange Network. IM Programme was also represented in the NoLIMITS Task Force. IM Programme Centre was responsible for preparing a Background document on modelling for the NoLIMITS workshop. The Programme Centre as well as other participants of the IM Programme participated in a NoLIMITS Workshop held at Brasenose College, Oxford, UK, 24-26 March 1999.

- IM Programme contributed to the Indicators of Forest Ecosystem Functioning (IFEF) project. Soil chemistry and input-output data from ICP IM sites which had indicated their interest in participating in the project were sent to IFEF. A combined dataset from ICP IM sites and other forest eco-system sites has been used to evaluate the relationship between the carbon-to-nitrogen ratio (C:N) of the soil organic horizon and nitrate leaching in runoff or seepage water. These results were published in a scientific paper.

- ICP IM will produce the following reports to the Working Group on Effects, August 1999:
  - Annual Report
  - ICP IM contribution to the joint report on temporal trends 'Trends in Impacts of Long-Range Transboundary Air Pollution'
  - Joint Report of ICPs and Mapping programme

  - IM Programme Centre will finalize the IM parts to the joint report: 'Trends in Impacts of Long-Range Transboundary Air Pollution'. ICP IM contribution is based on data on measured trends in bulk deposition, throughfall and soil water chemistry as well as modelled trends in soil and water acidification.

  - The ICPs and the Mapping Programme will produce a 1999 Joint Report for the WGE meeting. The report will contain a short general introduction as well as a review of the activities during the past year. The ICP IM contribution will be prepared by the Programme Centre.

- Scientific strategies to carry out data assessment on two priority topics have been developed:
  - Calculation of pools and fluxes of heavy metals at selected sites (lead by the National Focal Point of Sweden), and
  - Assessment of cause-effects relationships for biological data, particularly vegetation (lead by the National Focal Point of The Nethlands).

1.2 Activities and tasks prepared for 1999-2000

- Finalization of ICP M parts to the report:'Trends in Impacts of Long-Range Transboundary Air Pollution' (1999).
- Participation in inter laboratory comparisons organized by other ICPs (1999/2000).
- Participation in the activities of external organisations e.g. EU/NoLIMITS project and GTOS (1999/2000).
- Inclusion of quality controlled national data for 1998 in the IM database. Data was collected according to 1993-1996 IM manual and will still be reported accordingly (October 1, 1999).
- Processing of additional information (background info/site descriptions).
- Continuation of work on trends and budgets of S and N compounds.
- Preparatory work in two new areas according to agreed scientific strategies:
  - Calculation of pools and fluxes of heavy metals at selected sites.
  - Assessment of cause-effect relationships for biological data.

1.3 Future priorities of the programme

- Maintenance and development of a central ICP IM data base at the Programme Centre.
- Continued assessment of the long-term effects of S and N compounds in support of the implementation of emission reduction protocols, including:
  - assessment of trends;
  - calculation of ecosystem budgets;
  - dynamic modelling and scenario assessment.
- Calculation of pools and fluxes of heavy metals at selected sites (work has already started).
- Assessment of cause-effect relationships for biological data, particularly vegetation (work has already started).

1.4 List of published documents and reports 1998/99

IM manual:

Manual for Integrated Monitoring,1998. Finnish Environmen Institute, Helsinki, Finland. WWW-version: http://www.vyh.fi/eng/intcoop/projects/icp_im/manual/index.htm

Evaluations of international ICP IM data:

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Vanhala, P., Kapanen, A., Fritze, H. and Niemi, R. M. 1998. Microbial activity and biomass in four Finnish coniferous forest soils spatial variability and effect of heavy metals. Boreal Env. Res. 3: 287 295.
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1.5 Monitoring sites

The Integrated monitoring network covers the following twenty-two countries: Austria, Belarus, Canada, Czech Republic, Denmark, Estonia, Finland, Germany, Iceland, Ireland, Italy, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Russian Federation, Spain, Sweden, Switzerland, and United Kingdom. These countries have either on-going data submission from at least one monitoring site or the data submission is just starting. Switzerland will carry out the IM programme on a lower level and a new decision on the extent of IM activities will be made in

2002. Location of the IM monitoring sites with on-going data delivery are presented in Figure 1.1 (i.e. data from year 1994 received and continuation of the monitoring indicated).

In the database data is available from two additional countries: Hungary and Ukraine. The monitoring activities in Hungary have been suspended and Ukraine has been unable to submit data in the last few years.

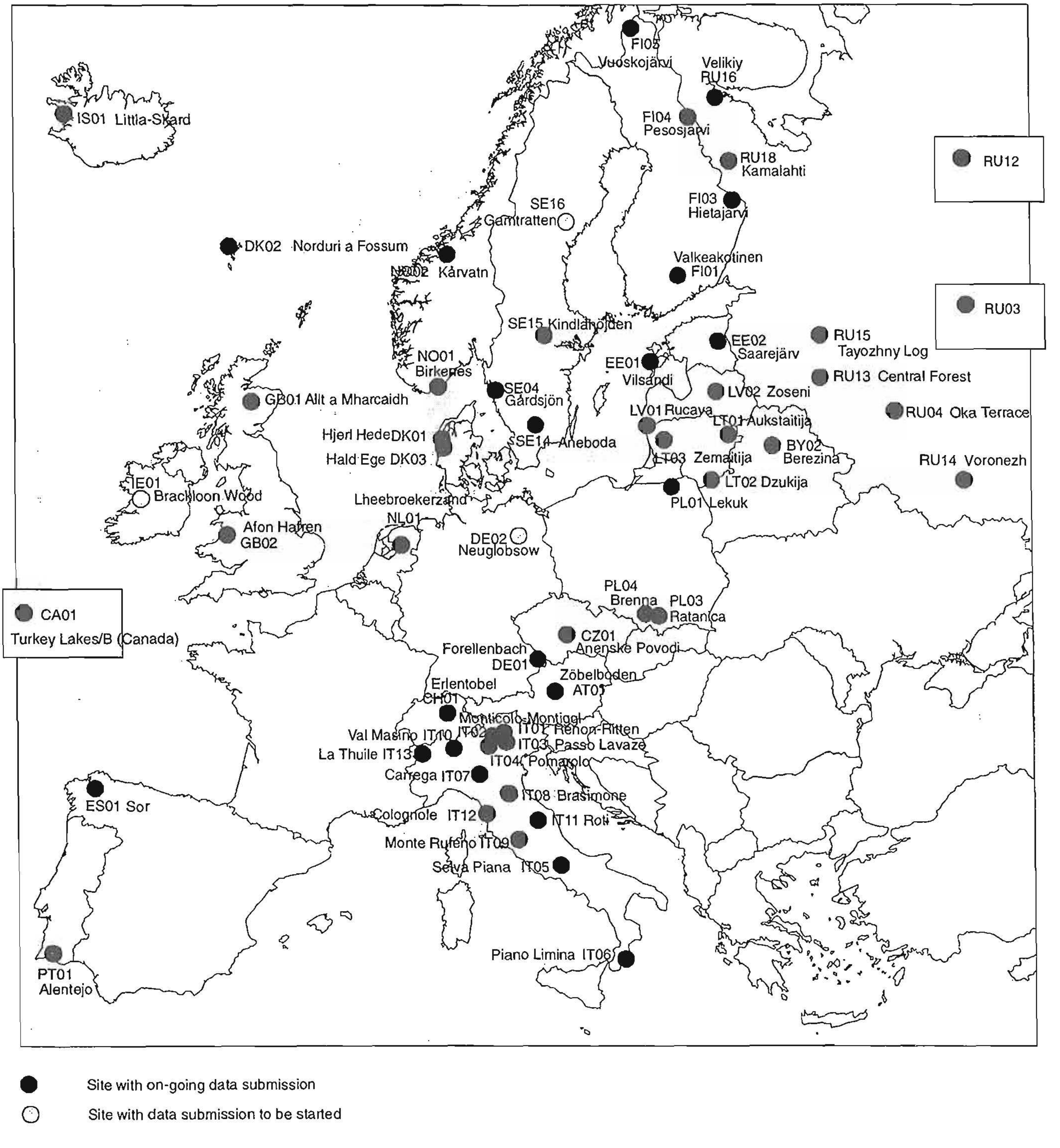

Figure 1.1 Geographical location of the Integrated Monitoring sites

1.6 Monitoring data

All in total, integrated monitoring data is at present available from 70 mostly European sites. An overview of the data reported internationally to the ICP IM Programme Centre and presently held in the IM database is given in Table 1.1. This means that data is also available from additional sites outside those presented in Figure 1.1. with on-going data submission. The additional sites have either been suspended or taken out of the IM network and used for regional monitoring. E.g. Sweden started with a number of monitoring sites but has since then made a decision to carry out integrated monitoring only on four sites, the other sites have been downscaled to regional monitoring sites. The number of sites with on-going data submission is about 50.

Table 1.1 Internationally reported data held presently in the ICP IM database.

AREA	SUBPROGRAMME															*							
	AM	AC	DC	MC	TF	SF	SC	SW	GW	RW	LC	FC	LF	RB	LB	FD	VG	EP	AL	MB	BB	BV	Info
	meteorol.	air chemistry	precip. chemistry	moss chemistry	throughf.	stemflow	soil chemistry	soil water chemistry	groundw. chemistry	runoff water c.	lake water c.	foliage chemistry	litterfall chemistry	hydrob. of str.	hydrob. of lakes	forest damage	vegetat.	trunk epiphytes	aerial gr.algae	microb. decomp.	bird inventory	vegetation inventory	
BY02	89-97	89-97	89-97				95-96			95-97													
CA01	88-96		88-96						88-96	88-96													
CH01	88-97	88-97	88-97		91-97				90-96	88-97	-	89			-	95-97							
CZ01	89-97	89-97	89-97	89	89-97					89-97	-				-								
DE01	90-97	90-97	90-97	90	90-97	90-97	90	90-97	88-97	90-97	-	90-97	90-97		-	90-97	90-95	92-95		94-97	91-96	90,95	
DK01			92-97		92		86	92-97		-	-			-	-								
DK02			97							97	-				-								
DK03			94-97		94-97		95	94-97		-	-			-	-		95						
EE01	95	94-97	94-97	94	94-97	94-97	94	94-97	95-96	-	-	94-97	94-97	-	-	94-95	94,97	94-96		94-97		94	
EE02	94		94-97	94-97	94-97	94-97	94-95	95-97	95-97	94-97	96	96	94-97			96-97	96	94-95	94,97	96-97			
ES01			92-93		92-93		92	92-93		91-93	-				-								modelling data
FI01	88-97	94-97	88-97	88-96	89-97	89-97	88-89	89-96		88-97	87-97	88-96	90-95		90-93	88-91	88-95	88-97		90	87-89	87	
FI03	88-97	93-97	88-97	89-96	89-97	89-97	88	89-96		88-97	87-97	88-96	90-95		90	88-91	90-95	90-97		90-91	87-89		
FI04	88-97	89-97	88-97	89-96	89-97	89-97	89	89-96		88-97	86-97	89-96	90-95			89-91	89-95	89-98		90-91	87-89		
FI05	88-97		88-97	91,96	89-97	89-97	88	89-96		89-97	87-97	88-95	90-95			88-91	89-95	89-97		90-91	88-89		
GB01	88-97	91-97	88-96				90		90-91	88-97	-				-								
GB02	88-97	91-97	88-97		88-91	88-91		90-91		88-97	-				-								
HU01	88-93	88-93	88-93	92-93	90-93	90-93	88		89-93	-	-	92	92-93	-	-								
IS01																						96	establ. 1996
IT01	93-95	93-95	93-97		93-97	93-97	93	93-97		-	-	93		-	-	92-97		92		93			
IT02	93	93	93-97		93-97	93-97	93	93-97		-	-	93		-	-	92-97		92					
IT03	92-97	93-97	92-97		94-97	94-97	93,95		95-97	-	-	93,97	94	-	-	93-97	95	92					
IT04	92-97	93-97	92-97		94-97	94-97	93,95		95-97	-	-	93,95	94	-	-	93-97		92					
IT05	97	97	97		97	97	95			-	-	97		-	-	97							
IT06		97	97		97	97	95			-	-	97		-	-	97							
IT07	97	97	97		97	97	95			-	-	97		-	-	97							
IT08		97	97		97	97	95			97	-	97		-	-	97							RW outside plot
IT09	97	97	97		97	97	95			97	-	97		-	-	97							RW outside plot
IT10	97		97		97		95			-	-	97		-	-	97							
IT11		97	97		97		95			-	-	97		-	-	97							
IT12	97	97	97		97	97	95			-	-	97		-	-	97							
IT13	97	97					95			-	-	97		-	-	97							
LT01	93-96	93-97	93-97	93	93-97		93	94-97	93-97	93-97							93-97	93,96	93,96			93	
LT02	93-96	93-97	93-97	93	94-97		93	94-97	93-97	93-97	-			93-97	-		93-97	93,96	93,96			93	
LT03	95-96	95-97	95-97		95-97		94	95-97	95-97	95-97				95-97			94-97	94,96	94,96			94	

- Subprogramme not possible to carry out

* or forest health parameters in former subprogrammes Forest stands/Trees

Internationally reported data held presently in the ICP IM database (cont)

AREA	SUBPROGRAMME															*							
	AM	AC	DC	MC	TF	SF	SC	SW	GW	RW	LC	FC	LF	RB	LB	FD	VG	EP	AL	MB	BB	BV	Info
	meteorol.	air chemistry	precip. chemistry	moss chemistry	throughf.	stemflow	soil chemistry	soil water chemistry	groundw. chemistry	runoff water c.	lake water c.	foliage chemistry	litterfall chemistry	hydrob. of str.	hydrob. of lakes	forest damage	vegetat.	trunk epiphytes	aerial gr.algae	microb. decomp.	bird inventory	vegetation inventory	
LV01	93-97	93-97	93-97	94	94-97	94-97	94	94-97	94-97	93-97	-	94-97	94-97	95-97	-	94-97	94-95	94-95		96			
LV02	93-97	94-97	93-97	94	94-97	94-97	94	94-97	94-97	93-97	93-97	94-97	94-97	95-97	95-97	94-97	94	94		96			
NL01	93-97	90-97	90-97	93-97	93-97	93-97	93,97	97	90-97	-	90-97	93-97	93-97	-	92-97	84-97					90-97		
NO01	87-97	87-97	87-97	92	89-97		86	89-97	87-88	87-97	-	86			-	91-97	86	86					
NO02	87-91	87-97	87-97	88	89-97		89	89-97		87-97	-	89			-	92-97	89						
PL01	88-96	88-96	88-96	88-90	93-96		88	93-96		88-96	88-95	88-90											
PL02				91			90-91				89-90	90-91				90-91	91						
PL03		92-94	93-94		93-94	93-94		91-94		93-94		-	92		-								
PL04	93	93	93-94y		93-94y					93-94y													y=yearly
PT01	88-95	89-97	94-97							90-97	90-97												
RU03	89-94	89-96	89-95																				
RU04	89-94	89-96	89-95	90										93-96		93,96	93	93		94-95			
RU05	89-93		89-93		89-93				90-91	89-93	93					90	90	90					
RU12	93-94	93-96	93-94																				
RU13	93	93-94	93																				
RU14	94	94-96	94-95																				
RU15	90-95	90	90-96	94	90-96	90-96	90		90-96	90-96	-			93	-		91	94					
RU16				89-90			89	89	89						93-96	93-96	91-94	89-94	93	94-95		91	
RU18			92-97	92	92-97	92-97	93	94-97	95-97	92	92-94	92				93	94	93		93			
SE01	83-91		83-94		92-93		82-90	84-95	84-93	84-95			91-92	88-95		87-92	82-93	83-92		83-95		87	
SE02	83-91		83-94		92-93		82-90	85-95	84-94	84-95			91-92	90-95		88-92	82-94	83-92	94	83-95		82	
SE03	83-91		83-94		92-93		88	87-95	85-94	84-95			91-92	91-95		87-92	84-91	84-90		85-97		89	
SE04	87-97	88-97	87-97	95	87-96		95	87-88	79-96	87-96	-				-	97	95	96	92-97	95-97			
SE05			83-94						83-92	84-95							83-93	83-93					
SE06								85-94	82-94	86-95	-				-		82-91	82-92		84-94			
SE07									82-93		-				-	87-92	82-93	82-92	89-92	83-93			
SE08			83-94						84-94	84-95						88-92	83-93		90-92	84-93			
SE09			88-94						86-92	88-95				87-95		88-94	86-94	86-91	90-94	87-93			
SE10			88-94						88-94	86-95				85-95		88-94	84-94	87-92	89-94				
SE11			83-92						82-94	84-95						88-94	82-94	87-92	89-94	83-93			
SE12			83-94						82-94	84-95						88-94	82-94	82-92	89-94	83-95			
SE13			89-94							89-95	-				-		89-94		92				
SE14	96-97	96-97	96-97	95	96-97			95-97	96-97	96-97	-		95		-	97	82-97	97	97	95-97			
SE15	97	96-97	96-97		96-97		97	95-97	97	96-97	-	97	95		-		96		97	95-97			
UA17	90, 93		93																				

2 IM data used for modelling environmental vegetation effects on a European scale

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2.1 Summary

The present paper is to be regarded as a plea for international co-operation in the provision of data that can be used to assess cause-effect relationships in the species composition of understorey vegetation. The analysis will primarily be focused on explaining the effects associated with different aspects of long-range transboundary air pollution (acidification, eutrophication and possibly heavy metal toxicity). On a European scale, this implies that the obvious influence of climatic difference has to be included in the analysis. Without a correction for climatic factors, the resulting models will be limited to a regional validity. The proposed method to construct the vegetation models is relying on multivariate statistical regression. For all species demonstrating a considerable amount of variance over the reported sites, the probability of occurrence will be calculated as a function of the observed variability in a number of environmental factors. Analysis of variance will subsequently reveal the factors that have the most prominent effect in the presence or absence of individual species. Once the models have been calibrated, the shifts in species composition can be calculated as a result of projected changes in the environment.

2.2 Introduction

Rationale for focusing on understorey vegetation

IMP monitoring sites are selected to represent more or less natural ecosystems, which are mainly characterised by their types of vegetation. Therefore, the most elaborately studied biological component of the ecosystem is the vegetation. Diversity and abundance in plant communities is relatively easy to quantify. Vascular plants are sedentary organisms subject to very direct and immediate interactions with the local abiotic environment. Small and herbaceous plants, shrubs and sapling trees, all belonging to the understorey vegetation, can be expected to react more swiftly and more dramatically to environmental change than mature trees.

At the 1998 IM Task Force Meeting in Tallinn it was decided to put more emphasis on our ability to conduct biological effect studies. In order to accomplish this, the Task Force requested the Dutch delegation to develop a plan to further enhance our abilities in this field and to take the lead in defining and mobilising the requirements.

A very fruitful meeting of Finnish, Swedish and Dutch delegates took place on December 10, 1998 in Stockholm. It was decided to start exploring possibilities for making biological effect models for understorey vegetation. These models should primarily explain the variation observed in species composition as a function of spatial and temporal variations in the environment. At a later stage, the constructed models may hopefully also be used to predict changes in the vegetation as a consequence of environmental policy measures.

2.3 Modelling options

Modelling of biological effects requires a multi-variate approach

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Changes in ecosystems, populations and species can be attributed to combinations of environmental stresses. Predictive studies focusing on a single stress factor, will generally produce results that only partially reflect reality. It is essential to include the influence of a variety of environmental factors, especially on a continental scale, in modelling biological effects. With respect to the species composition of plant communities, the following categories of environmental habitat variables are most probably of importance:

- Climatic factors (e.g.: temperature, irradiation, precipitation)
- Soil and soilwater properties (e.g.: soil type, acidity, nutrient availability, groundwater table and water retention capacity)
- Toxic pollution (bioavailable pollutant levels, mainly in soil)

2.3.1 Mechanistic modelling

Most models that relate to the ecological effects of more than a single environmental variable are functionally mechanistic of nature. These models reflect a trade-off between the geographical scale of the model, the types of ecosystems taken into account and the complexity of the processes treated. It is considered questionable (Latour et al. 1993) if mechanistic modelling can predict the ecological effects of the various environmental perturbations related to long-range air pollution on the required international scale.

2.3.2 Probabilistic modelling

As the only alternative, the effects of variations in a multitude of environmental variables may be estimated by applying a probabilistic approach. Multivariate regression can be used to formally express the occurrence probability of individual species as a function of the variability in predefined environmental factors and possibly their interactions. This type of regression modelling is actually based on analysis of covariance between the occurrence of species and the variance in a variety of habitat factors. Therefore, species that are very general over the entire range of studied habitats and species that are very rare will not be modelled adequately. This type of empirical modelling has been used in The Netherlands with considerable success.

2.4 Modelling examples

Latour and Reiling (1993) developed a conceptual, species-centred, multiple-stress MOdel for VEgetation (MOVE). This model explains the occurrence of individual species of plants as a function of soil properties: nutrient availability, pH and moisture content. The MOVE model has been extended by adding a soil module predicting the environmental variables as a consequence of environmental policy scenarios. The dynamic soil model SMART (De Vries et al. 1989) is used to generate the required abiotic input. The combined model (SMARTMOVE) enables a prediction of the associated changes in the species composition of the vegetation (Figure 2.1).

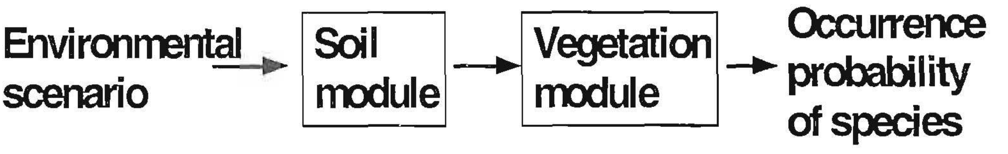

Figure 2.1 Schematic representation of the MOVE-model.

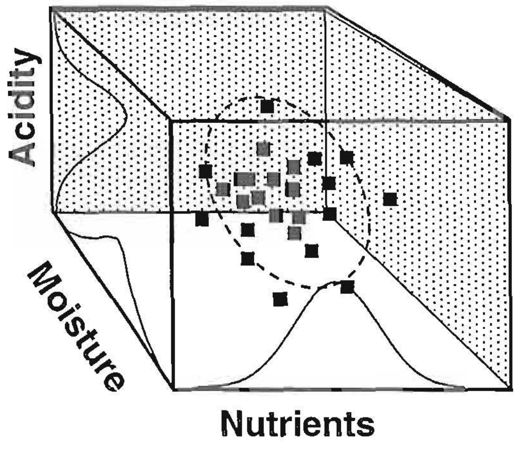

Figure 2.2 A multi-dimensional hyper-volume with dimensions defined by variables related to acidification, eutrophication and desiccation. Dots in the hyper-volume refer to the occurrence of a particular species. The bell-shaped solid lines are the probability densities projected on the abiotic axis. The dashed "95% probability response volume" describes the "normal operating range" for the species.

In order to calibrate the MOVE model, the response curves of 700 Dutch plant species have been constructed for the combination of soil moisture content, nutrient availability and soil acidity (Figure 2.2) (Wiertz et al. 1992). The calibration process was executed by applying Gaussian logistic regression models on an extensive database developed in a revision of the Dutch classification system for plant communities. This database consisted of 17,000 local vegetation inventories. No measured data were available on the associated abiotic site factors. Using the method suggested by Ter Braak and Gremmen (1987), a projection was made to assess the abiotic factors from Ellenberg indication values (Ellenberg et al 1991). Ellenberg numbers indicate the relationship between the occurrence of a particular plant species and nutrient availability, acidity, soil moisture content, salt dependency, light conditions and temperature. These values have been assigned to most plant species endemic to western and central Europe. The abiotic site factors belonging to some local inventories are calibrated against the Ellenberg numbers averaged over all species recorded. Next, the frequency of occurrence for every species is established as a logistic function of the calculated abiotic factors (Jongman et al. 1987).

Recently, the application of probabilistic vegetation models has been extended to include a prognosis on the changes of vegetation on a European scale, as a consequence of a climatic change scenario for the coming 50 years (Alkemade et al. In Prep.). In order to construct the species-response curves for dependency of the main European plant species towards climatic factors, the presence/absence data from the Atlas of European Flora (Jalas, 1979-1989) were combined with the IIASA database (Leemans et al. 1991) on mean monthly values for climatic variables.

2.5 Objective

As has been demonstrated by the examples, it is most likely that a vegetation model reflecting changes in climate, acidification, eutrophication and perhaps soil toxicity can be made to work on a European scale. Applying a MOVE-like approach as a stand-alone model will provide information on the causative factors most prominently explaining the observed differences in species composition. Since specific abiotic factors are linked to the occurrence of long-range transboundary air pollution, cause-effect relationships can statistically be established. On a European scale, the vegetation module will need species-response curves for a wide variety of plant species and an extensive set of environmental variables. By including a range of categorical physico-geographic regions, the model will enable the analysis of causes for regional differences in the vegetation.

The possibilities for the application of predictive models are strongly depending on the scenario validity of the input models on a European scale. The SMART-model, that may act as one of the input sources to the vegetation model, has already specifically been developed on a European scale in the context of critical-load studies. Climatic change models are also available on a continental scale (e.g. the IMAGE2-model), and heavy metals toxicity models using generic species sensitivity distributions (SSD) are in the process of being developed.

Ecosystem monitoring programmes, such as the ICP IM programme, are likely to be very suitable for providing the required data on a European scale. Since ICP IM may provide actual measured data on the required environmental factors, the controversial use of Ellenberg-like indicator values may be omitted. In this respect, the IM data may be used for an extended validation of the mentioned vegetation models.

2.6 Data requirements

In order to construct this type of effect models, the availability of a comprehensive dataset is a prerequisite for calibration purposes. For each site used in the calibration process, the data should contain a complete set of environmental observations in conjunction with a list of occurring species. The species lists may be in the form of a binary absence/presence table or in the form of reported abundance values. If the resulting species models have to be applicable on a European scale, the calibration set of data should cover wide ranges of variation in the habitat discriptors and a large number of observation series. For regional application, the data requirements are considerably less stringent.

From the test runs conducted in the European climatic model, it can be concluded that the climatic factors determining the diversity in plant communities are best represented by:

1) Local monthly average temperature of the coldest month of the year
2) Annual summation of the daily average temperature above 5 °C
3) "Alpha moisture index", which is the ratio of actual and potential annual evapotranspiration
4) Annual precipitation
5) Length of the growing season in number of days
    - Start growing season: T > 5 °C and precipitation = ½ potential annual evapotranspiration
    - End growing season: T < 5 °C or soil moisture drops below wilting point
6) Daily average temperature during the growing season

If the location of the station (map coordinates) is known, all of these data can be based on the updated version of the IIASA database for long-term (30 year) mean monthly values of climatic variables. These data are available on a global terrestrial grid interpolated with a resolution of 0.5° longitude by 0.5° latitude. However, it is preferred to base these data on local or near local observations in a shorter time frame (e.g. max. 5 year).

The influence of long range transboundary air pollution (in the sense of acidification and nitrogen enrichment) and soil properties (in the sense of buffer capacity and moisture availability) can be added to the model by including the following variables:

7) pH of the soil solution
8) Nitrogen content of the soil solution
9) Clay fraction of the soil
10) Organic carbon fraction of the soil
11) Depth of the groundwater table at the start of the growing season or the average soil moisture of the rooting zone
12) Heavy metal content of soil or soil water

Next to climatic and soil properties it is well established that the nature of a local plant community is strongly depending on categorical site characteristics. Some examples are given in the following bullet list:

- The European FIRS-project (Forest Information from Remote Sensing) identified that the nature of the plant communities is mainly determined by the physico-geographical region.
- Shaded north facing slopes have different vegetation than south facing open terrain.
- Understorey vegetation under dense forest canopy will be characterised by species that are able to cope with low light conditions.
- Regions which are recently (within 3-5 years) highly disturbed by human or accidental interference (mowing, burning, sod cutting, cattle grazing, felling etc) have a species composition which is of more opportunistic nature than areas without discontinuities.

Proper predictors for species composition should therefore also contain information on a set of categorical site descriptors pertaining to regions, light exposure, disturbance and vegetation type:

13) Physico-geographical region:
According to the FIRS project, the 22 physico-geographical regions identified in Europe are characterised by differences in 1) climate, 2) altitude and 3) soil condition. Both differences in climate and altitude are covered by the variables included in the climatic description. Soil condition is related to soil type as defined by FAO (United Nations Food and Agricultural Organisation). The following soil conditions are recognised:

	Soil Condition	FAO Soil Type
a)	Poor	Lithosols, Regosols, Xerosols, Yermosols
b)	Marginal	Acrisols, Rendzinas, Podzols, Rankers
c)	Intermediate	Podzoluvisols, Vertisols
d)	Good	Cambisols, Chernozems, Phaeozems, Kastanozems, Luvisols, Greyzems, Arenosols, Andosols
e)	Hydromorphic	Gleysols, Fluviosols, Planosols
f)	Organic	Histosols, Solonetz
g)	Saline	Solonchanks

14) Local shading conditions:
   a) Continuously exposed to direct sunlight:
      no canopy – south facing
   b) About half-time exposed to direct sunlight, rest lightly shaded:
      No canopy – east / west slope, or very light canopy
   c) Hardly ever exposed to direct sunlight, lightly shaded
   d) Hardly ever exposed to direct sunlight, medium shaded
   e) Hardly ever exposed to direct sunlight, heavily shaded
   f) Never exposed to direct sunlight and lightly shaded
   g) Never exposed to direct sunlight and medium shaded
   h) Never exposed to direct sunlight and highly shaded

15) Degree of disturbance :
   a) No disturbance observable nor recorded
   b) Incidental disturbance more than 5 years ago
   c) Incidental disturbance more than 3 years ago
   d) Incidental disturbance more than 1 year ago
   e) Regular disturbance once yearly
   f) Regular disturbance several times per year

16) Vegetation type:
   a) Grassland
   b) Shrubland
   c) Heather
   d) Deciduous young forest
   e) Deciduous mature forest
   f) Coniferous young forest
   g) Coniferous mature forest

2.7 Availability of required data

All required data topics are essentially covered in the IM programme. Especially, the data used to describe the climatic and categorical site factors may need some recalculation and coding. However, the data potentially available in the IMP databases at the Finnish Environment Institute may not be sufficient in number and variability to cope with a reliable regression involving a sufficiently wide variety of habitat factors. For each predictor term added to the regression equation, preferably several hundreds of observational series have to be added for the calibration process. However, it is most likely that the required data are, or can be made available on a regional scale by the National Focal Centres partaking in the ICP IM monitoring programme. In most countries, additional data will be available through national ecological monitoring programmes and local research projects.

2.8 Plea for Co-operation

I would like to ask all IM participants to co-operate in providing the data indicated above for as many stations and sub-stations as possible. I would prefer to receive the data in the form of a single EXCEL-spreadsheet per station/date. The spreadsheets should contain single rows of data for each vegetation species present, as well as single rows of data for each of the required habitat variables. For the method of coding and the number of descriptive data columns, the supplier is referred to the prescribed method of coding for the IM subprogrammes in the new IM manual (Manual for Integrated Monitoring 1998). The full reporting format B1 for the VG subprogramme can also be used (an ASCII file which can be read into EXCEL). The following columns should minimally be included:

AREA	STATION	DATE yyyymmdd	VARIABLE	CODE LIST	VALUE	UNIT
NL01	0001	19970000	SPECIES code	B4	x	Abundance (BB-score)
NL01	0001	19970213	SPECIES code	M2	xxx.xx	Species density (/unit area)
NL01	0001	19970213	SPECIES code	B4	1	Presence (0/1)
NL01	0001	19970000	Annual precipit.		xxx.xxx	mm/yr
NL01	0001	19970000	Soil cond.		poor	cat.
NL01	0001	19970213	N-total		xxx.xxx	mgN/L
NL01	0001	19970213	pH		7.2	pH unit

In order to be able to start the statistical analysis by the end of 1999, I would like to stress the need for timely submission of data.

2.9 Planning and provisional time table

Action	Time table
Data submission by NFPs	June-December 1999
Presentation of first results	April 2000
Updating of database	May-September 2000
First evaluation report	December 2000

2.10 References

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3 Strategy for assessment of heavy metal stores and fluxes

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3.1 Heavy metals at the regional and global scales

The distribution of heavy metals by air over large land areas has become an environmental issue in Europe. The steady accumulation of heavy metals in soils will eventually have detrimental biological effects on ecosystems or affect water or food quality for human consumption. The environmental analysis has moved from local metal-emitting industries to low dose situations on the regional and global scales. Priority metals in UN ECE initiatives are Pb, Cd and Hg, while Cu, Zn, As, Cr and Ni should be considered at later stages (Annex 1, Manual for Integrated Monitoring 1998). Although heavy metals are optional in the IM Manual (Table 3.1), the current interest in critical loads may encourage measurement of metals. In fact, metals are already reported to the IM data base from a number of countries.

At the 1998 ICP IM Task Force meeting in Tallinn it was decided to promote heavy metal assessments in ICP IM with Sweden as lead country. The working plan was further discussed by Finnish, Swedish and Dutch experts at a meeting in Stockholm on December 10, 1998.

Table 3.1 Sample types proposed for heavy metal analysis in Manual for Integrated Monitoring (1998). Optional measurements in the manual are Fe, Mn, As, Cd, Cr, Cu, Mo, Ni, Pb and Zn. Hg is suggested only for biotic samples and soil samples. Pb, Cd and Hg have highest priority.

Subprogramme	Sample type
AC, Air chemistry	aerosol
PC, Precipitation chemistry	aqueous
MC, Moss chemistry	biotic
LF, Litterfall chemistry	biotic
TF, Throughfall chemistry	aqueous
SF, Stemflow chemistry	aqueous
FC, Foliage chemistry	biotic
SC, Soil chemistry	soil
SW, Soil water chemistry	aqueous
GW, Groundwater chemistry	aqueous
RW, Runoff water chemistry	aqueous
LC, Lake water chemistry	aqueous

3.2 Heavy metal assessments at ICP IM sites

ICP IM data on heavy metals would be valuable on three levels of ambition:

1. Analysis of concentrations in aqueous and biotic media
2. Input-output budgets, fluxes and stores
3. Provision of data for CL modelling (critical loads)

By systematically compiling quality assured metal concentrations in a large number of aqueous and biotic media in ICP IM catchments, Ukonmaanaho et al (1998) were able to draw conclusions on metal processes in the ecosystem. Levels of metals in relation to other sites, enrichment in throughfall, retention in upper soil layers, retention in the catchment, accumulation in biomass and presence/ absence of temporal relations between metals in deposition and in other aqueous media were successfully analysed.

Small catchment studies are especially well suited for input-output budgets. Indeed, this is the main rationale for this type of study. Rates of accumulation or release of metals from forest systems can be estimated. Dividing input/output flux balances by soil stores results in crude linear predictions for these stores (Aastrup et al 1991). Detailed flux estimates for different soil compartments refine the picture of metal allocation within the system. Studies of hydrologic flow paths through soils and discharge areas improve the understanding of metal mobilisation to aquatic systems (Aastrup et al 1995). In cases where runoff data are missing, very useful compilations can be based on forest studies on the plot scale (Bergkvist et al 1989). Flux estimates for soil water and ground water require water flow calculations, which are exercises of their own.

The cited papers above may serve as prototypes for analysis of concentrations and mass balances. Mercury constitutes a special difficulty as its measurement in water samples is costly and requires advanced analytical methods and clean techniques. This effort will probably only be performed in a few of the ICP IM sites. However, it should be remembered that Hg is a priority element which will stay as an environmental hazard for a long time. The ICP IM approach is appropriate for the integrated assessment needed for Hg (Aastrup et al 1991, Munthe et al 1998), although there are special complications in the biogeochemistry. Determination of total Hg in soils and biotic samples is not very difficult and quite feasable in the IM programme. Fortunately, in case of Hg, litterfall constitutes a very great part of the input which is not very demanding on the methodology.

Nitrogen is stored in soils and biota in much the same way as metals, although implications for biological productivity are much different. The work on nitrogen and metals could well be combined.

3.3 Critical loads for heavy metals (CL)

There is a European initiative for a Protocol on heavy metal emissions based on the critical loads concept (CL). Methods of assessment for terrestrial and aquatic ecosystems have been discussed at an UN ECE workshop in Bad Harzburg, Germany in 1997 under the Task Force on Mapping (Umweltbundesamt 1998). Critical loads are levels of input below which harmful effects no longer occur. The workshop will be reassembled this autumn. The assessment is a twofold exercise, on the one side the derivation of effect-based critical limits in soils or other media and, on the other side, the implementation of mass balance models for mapping (de Vries and Bakker 1998). The IM programme would be very adequate to provide data for the mass balance models and to take part in the development of critical limits by associated research.

3.4 CL modelling

A large part of the data required to build mechanistic mass balance models can be provided at least from some of the ICP IM areas. Models may be of steady state type or more complicated dynamic types (de Vries and Bakker 1998). As changes in heavy metal levels are slow due to the extensive storage in soils, a time frame of 50 to 100 years should be applied. Models with a slow dynamic rather than steady state are appropriate. The models will include mechanistic descriptions of processes such as ion exchange, weathering and immobilisation/release in organic matter and Al, Fe, Mn-oxides. Generally, there is a sound scientific basis for the models, although the kinetics of immobilisation/release processes are poorly known. However, there are some major unknowns in the case of Hg. Swift redox processes, gaseous re-emissions, complexation with organic matter and methylation are more or less important obstacles in Hg modelling. The role of the IM programme in the modelling work could be to provide the modelling community with data.

3.5 Ecotoxicological assessments in ICP IM

Soil microorganisms were pointed out at the Bad Harzburg workshop as the most important receptors for metal effects in non-agricultural soils (Umweltbundesamt 1998). Higher organisms may be exposed in the food-chains. In this later context Scandinavian countries have focussed on Hg in fish of boreal forest lakes, considered a human health problem when content exceeds 0.5 microg/g. The quality of ground water affected by soil pollution should be classified with respect to standards for drinking water.

Critical limits for various receptors have usually been obtained by experimental exposures. Some biological field observations may also have general indication value, such as litter decomposition, but usually observed changes cannot be ascribed to levels of specific pollutants in the field situation. Spatial patterns of pollutants with correlations to patterns in biological variables can reveal effects in some cases. Current assessments of critical limits in soils and vegetation are summarised in Table 3.2 according to de Vries and Bakker (1998), but more knowledge on low level and long-term effects under realistic field conditions is necessary. Some methods of sub-lethal toxicity assessments on aquatic organisms are proposed in the IM Manual, but various approaches to understand the low-dose situations are needed.

The Bad Harzburg workshop adopted a resolution that pore water concentrations are more adequate exposure variables than total contents for soil organisms and plants. However, most soil microbial toxicity tests have been related to total contents, which is also practical for chemical analysis. Uptake in plant roots is more clearly dependent on the pore water contents. Functions describing the relation between total contents and solution concentrations might solve the problem. In the application of critical loads to ICP IM areas we might choose to accept critical limits provided by other authors (Table 3.2) and direct our efforts on the mass balance models. On the other hand, we might choose to take a critical view on the critical limits and help to improve that part as well. Some values in Table 3.2 are even lower than natural concentrations, which indeed is questionable.

Table 3.2 Concentrations at critical limits for different media and receptors in forest systems compiled by de Vries and Bakker (1998).

	Pb	Cd	Cu	Zn	Hg
Humus layer-microbiota (microg/g)[1)]	50	0.35	2	30	0.075
Mineral soil-microbiota (microg/g) [1)]	-	-	6	17	-
Humus layer-invertebrates (microg/g) [1)]	15	1	10	50	0.25
Foliage-phytotoxicity (microg/g)[2)]	3	0.5	2	10	0.1
Soil solution-plants (microg/L)	15	2	2.5	25	-

[1)] Lowest Effect Concentration (LOEC) from literature survey of field and laboratory studies, divided by safety factor of 10.
[2)] LOEC for crop plants of intermediate sensitivity with safety factor of 10. Forest trees tend to have higher values.

3.6 Data currently in the data base

At present, sixteen countries and thirty-six ICP IM areas have delivered heavy metal data to the IM data base. Metal deposition is reported from most of these sites often including throughfall and stemflow. Metals in runoff are only reported from eight sites and metals in soil, soil water and ground water from a few sites. Reported time series extend over 1 to 9 years. The choice of metals varies, Pb, Cd, Cu and Zn being most common and As, Cr, Ni added in some cases. Unfortunately, Hg is usually missing. Moss data is available from twenty-four sites. Litterfall seems to be completely lacking from the data base, which is a great drawback. However, we know that more data exist on the national level.

An initial task is to get an overview on the existing data and form an opinion on their quality. Member countries will be asked to report missing data. We should also explore the possibility to get metal data from catchments outside the ICP IM programme in some countries.

3.7 Quality assurance and quality control (QA/QC)

The determination of trace metals in water, soils and biomass requires avoidance of contamination during sampling, pretreatment and chemical analysis. Operations more or less close to detection limits put special demands on quality control. There must be procedures to handle values below detection limits in calculations (Ukonmaanaho et al 1998). QA/QC procedures must be well documented in a heavy metal program. Necessary measures are thoroughly described in chapter 8 of the Manual for Integrated Monitoring (1998). Specified field methods should be followed remembering that very large errors might arise from this part of the work. Laboratories of chemical analysis should preferably be certified under an accreditation system and interlaboratory ring tests performed. Detection levels for different trace metals at the laboratories should be reported. These procedures are the responsibility of NFPs, but there might be reason to organise an international ring test to ensure comparability of data.

3.8 Work schedule

Sweden has volunteered as lead country, but active assistance from 1-2 other NFPs would be needed. Application of hydrological models in flux estimates and organising ring tests could be tasks for different NFPs. The IM Programme Centre compiles data from the data base and helps with communications.

Proposed work schedule:

Action	Timetable
Compilation of data report on concentrations	TF meeting 2000
Water flux estimates on plots	TF meeting 2000
Ring test on soil and water samples	During 2000
Data report on metal concentrations, budgets and stores	TF meeting 2001
Data for CL modelling	TF meeting 2001 and later

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WATBAL: A model for estimating monthly water balance components, including soil water fluxes

4

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4.1 Introduction

One of the main objectives of the ICP IM programme is to monitor the mass balance of major chemical substances within the ICP IM sites (Manual for Integrated Monitoring 1998). In order to calculate a mass balance, the fluxes of the chemical substance to and from the system, and within the system in more detailed balances, need to be known. The flux of a substance is calculated from the concentration of the substance and the hydrologic flux. The data necessary to calculate the monthly inflow fluxes to ICP IM sites, total deposition, are provided by the *Precipitation Chemistry* (*PC*), *Throughfall* (*TF*) and *Stemflow* (*SF*) subprogrammes. The outflow fluxes at the catchment-scale can be calculated from the *Runoff Water Chemistry* (*RW*) subprogramme. The hydrologic fluxes in these subprogrammes are relatively easily measured as precipitation and runoff. However, measurement of the hydrologic outflow flux at the plot-scale, percolating soil water, is much more difficult.

The substance concentration data in the *Soil Water Chemistry* (*SW*) subprogramme are provided by the monthly chemical concentration values from soil water samples collected by lysimeters. However, suction cup lysimeters can not be used to measure the soil water flux because the volume (and therefore area) of soil from which the sample is drawn is unknown and varying. Although the volume of water collected with zero tension lysimeters can be used to calculate a hydrologic flux value, such values are probably inaccurate. The degree of disturbance and severing of roots that is required to install zero tension (gravity) lysimeters, even in soils where they can be installed (i.e., relatively stone-free soils), modifies the hydrological properties of the soil. Even when zero-tension lysimeters are installed horizontally into the profile from a soil pit so as to minimise the disturbance to the soil above the collection surface of the lysimeter, the mere presence of the lysimeter probably modifies percolating water flow paths. Furthermore, there is usually high small-scale variability in sample volumes collected with suction cup lysimeters (Starr 1985) as well as in soil water hydrologic fluxes.

The difficulties in obtaining a reliable measure of the soil water flux in the field can be overcome by using soil hydrological models. The laws controlling the movement of water through a porous media such as soil are relatively well known and physical in nature. This, in theory, enables rather reliable process models of soil water fluxes to be made. However, many of the processes are complex and process models require complex input data and parameter values to be run. Such data may be available for a limited number of ICP IM sites but are not collected as part of the basic ICP IM programme. The IM manual suggests using a "simple [soil] water balance" model to estimate the monthly soil water hydrologic flux values. However, no guidelines are given.

In this report, I briefly describe such a soil water balance model, WATBAL, and present some results. A more detailed description of the model, as well as how to derive radiation-based evapotranspiration values for any sloping surface and soil available water capacities for differing soil type, is presently being prepared.

4.2 Model description

WATBAL is in the tradition of the water balance calculations developed by Thornthwaite (Thornthwaite and Mather 1957, Xu and Singh 1998). It is an "end-of-the-month" book keeping of the monthly precipitation inflow, evapotranspiration and drainage (soil water flux) outflows, and changes in soil water storage:

$$P = ET + R \pm \Delta SM$$

where: P= precipitation, ET= evapotranspiration, R= runoff (soil water flux), and $\pm \Delta SM$ = changes in soil moisture storage. All units are in mm of water per month.

The model is based on a series of algebraic equations, many of which are conditional to ensure rational results. Evapotranspiration is calculated from insolation (Global radiation submodel) rather than temperature (cf. Thornthwaite) and can be applied to sloping surfaces of any orientation. The insolation values are calculated using a statistical relationship between solar radiation at the top of the atmosphere and that received at the surface (insolation) derived by Bonan (Bonan 1989). The relationship was derived using Scandinavian weather station data and its validity to other regions should be checked. Monthly snowmelt, which is added to the precipitation input, is also handled in a submodel.

Precipitation (plus any snowmelt) is evaporated at the potential evapotranspiration (*PET*) rate. If the air temperature is 0°C, then *PET* equals zero and the precipitation (snowfall) accumulates as snowpack. If *PET* is greater than precipitation (+snowmelt), the unsatisfied part of the evapotranspiration demand is transferred to the water stored in the soil. The evapotranspirative withdrawal of soil water may take place at the *PET* rate or at a reduced rate, the actual evapotranspiration (*AET*) rate, depending on a relationship determined by the moisture content and the available water capacity (*AWC*). The *AWC* is the product of the water holding capacity of the soil, which is determined by soil texture (humus type in the case of the organic horizon), and horizon thickness. Evapotranspirative withdrawal of soil moisture can only take place from the rooting zone; losses from the soil beyond the rooting zone only take place through drainage. If precipitation (+snowmelt) is in excess of *PET*, then the excess goes to fill the storage capacity of the soil. If the *AWC* is filled then any further excess of precipitation (+snowmelt) goes to form drainage, i.e., the soil water flux from the soil layer in question.

4.3 Input data requirements

The data required to run WATBAL are readily available and most are collected as part of the ICP IM programme. A climatic data input file, parameter values and initial values for some variables are needed to run WATBAL. Initial values (i.e., values at start of the model run) are needed for accumulated potential water loss, soil moisture content, and the amount of snow on the ground. Guidelines for obtaining these values will be given in a latter detailed description of WATBAL (In prep.), as well as transfer functions for estimating the *AWC* from soil type and texture data. The long-term maximum and minimum air temperatures for the warmest month of the year as well as latitude and a temperature at which snowfall melts (usually 0°C) are also needed. The monthly direct radiation beam tilt factors, R_b, which remain constant from year to year, and the site diffuse radiation tilt factor, R_d, are needed to calculate the global radiation for sloping sites. For non-sloping sites, the monthly R_b, values = 1 and R_d = 0. A spreadsheet program for calculating sloping surface R_b and R_d, values from readily available data will be included in the forthcoming detailed description of WATBAL. For sites with snowfall, an albedo value for the snow cover is needed, and again, suggested values will be included in the WATBAL detailed description. The monthly climatic data file for the period of interest should contain precipitation, mean air temperature and cloudiness (tenths of sky covered). These data are readily available from weather stations.

4.4 Model output and some results

WATBAL output includes monthly values of: *PET*, *AET*, global radiation, water equivalent of snow cover, snowmelt, soil moisture content, and the soil water flux. The monthly evaporative (*AET-PET*) and soil moisture (soil moisture content-*AWC*) deficits can be calculated from these output data. These deficits, which are measures of drought stress, may be useful in explaining the temporal variability in the ground vegetation cover, tree growth, needle chemistry, and soil microbiological activity for example. The monthly output values, as well as the precipitation input values, can all be presented graphically or in tabular form and can be exported for use in third party programmes. The model has so far been validated using data collected from the Finnish Valkea-Kotinen (FI01) and Hietajärvi (FI03) IM sites.

The effect of slope and orientation on global radiation is shown for a plot in the Valkea-Kotinen catchment assuming it is horizontal and using its true slope and orientation (Figure 4.1a). The WATBAL modelled global radiation values were highly correlated (r=0.99) with measurements recorded at the nearby Jokioinen weather station.

Zero tension lysimeters have been installed in some of the permanent monitoring plots in the Hietajärvi catchment. The fluxes measured with the zero tension lysimeters installed at c.15 cm depth below the mineral soil surface (i.e., the percolation from the humus layer+15 cm layer) compare closely with soil water fluxes modelled by WATBAL for the humus layer+20 cm soil layer (Figure 4.1b).

Soil moisture contents (m^3m^{-3}) have been continuously measured (hourly) at both Valkea-Kotinen and Hietajärvi since August 1996 using a TDR system and automatic datalogger. The mean daily moisture content of the last day of the month measured in the humus layer and at c.15 cm depth in the mineral soil were used to calculate the moisture content in mm for the humus+20 cm mineral soil layer. The moisture contents based on the TDR measurements and those modelled by WATBAL are compared in Figure 4.1c (Hietajärvi) and in Figure 4.1d (Valkea-Kotinen). The estimated *AWC* value for the humus+20cm layer used for Hietajärvi was 46 mm and that for Valkea-Kotinen 41 mm. The monthly WATBAL soil moisture values follow the "measured" soil moisture contents rather well at both ICP IM sites. The difference in the soil moisture content between the "measured" and WATBAL modelled values at Hietajärvi may indicate that the estimated *AWC* value used in WATBAL was too high for this soil.

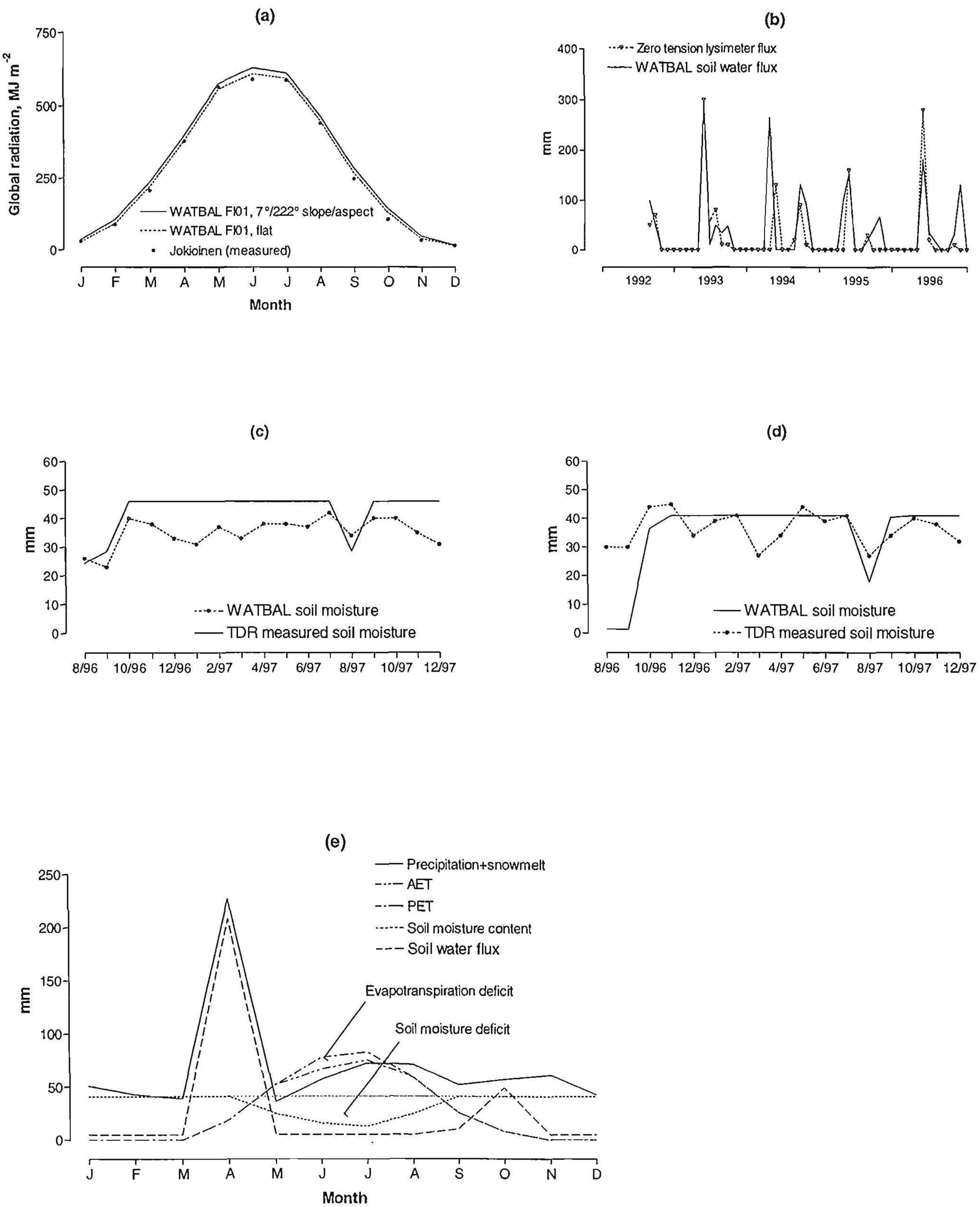

Figure 4.1 WATBAL average (1989-1992) monthly global radiation at Valkea-Kotinen (a), monthly soil water fluxes from humus+20 cm and zero tension lysimeter fluxes, Hietajärvi, August 1992-December 1996 (b), monthly soil moisture contents of the humus+20 cm layer and values based on TDR measurements, August 1996-December 1997, at Hietajärvi (c) and Valkea-Kotinen (d), and average (1989-1992) monthly water balance components for Valkea-Kotinen (e). For further details, see text.

As an example of the output possible from WATBAL, the long-term (1989-1997) average monthly water balance components calculated for the humus+20 cm layer at Valkea-Kotinen are presented in Figure 4.1e. The results indicate that of the annual rainfall+snowmelt input to the humus layer+20 cm soil layer, 53% left as evapotranspiration and 47% percolated to deeper in the soil. Percolation was confined to the spring snowmelt and wet autumn period only. During summer there was no soil water flux and the soil moisture storage is reduced by evapotranspiration demand of the stand. The annual evapotranspiration deficit averages 19 mm and the annual soil moisture deficit averages 87 mm.

4.5 Conclusions

WATBAL provides a means of calculating the water balance components for a soil and at a suitable time interval (monthly) for ICP IM sites. Most importantly, WATBAL can provide an estimate of the monthly soil water flux, a flux vital for making mass balances but which is difficult to measure.

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INTERNATIONAL COOPERATION

8th Annual Report 1999

UN ECE Convention on Long-Range Transboundary Air Pollution

International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems

The Integrated Monitoring Programme (ICP IM) is part of the Effects Monitoring Strategy under the UN ECE Convention on Long-Range Transboundary Air Pollution. The main aim of ICP IM is to provide a framework to observe and understand the complex changes occurring in the external environment.

This report summarizes the work carried out by the ICP IM Programme Centre and several collaborating institutes. The emphasis of the report is in the work done during the programme year 1998/99 including:

- a short summary of previous data assessments
- a short status report of the ICP IM activities, content of the IM database, and the present geographical coverage of the monitoring network
- a documentation of the scientific strategies to carry out data assessment on two priority topics:
  - assessment of heavy metal pools and fluxes
  - assessment of cause-effect relationships for understorey vegetation
- a description of the WATBAL-model for estimating monthly water balance components, including soil water fluxes.

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